Arnold Schwarzenegger
Governor

CARBON SUPPLY FROM CHANGES IN MANAGEMENT OF FOREST, RANGE, AND AGRICULTURAL LANDS IN CALIFORNIA: FOREST FUEL REDUCTION

ADDENDUM TO
PIER FINAL PROJECT REPORT

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Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California:

Forest Fuel Reduction [1]

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[1] This report serves as an update to Chapter 1, Section 5 of an earlier report sponsored by EPRI and the California Energy Commission (Brown et al. 2004, Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California, report by Winrock International to the California Energy Commission - PIER Energy-Related Environmental Research [publication 500-04-068F]).

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Abstract

This report serves as an update to earlier analyses sponsored by EPRI and the California Energy Commission (Brown et al. 2004, Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California, report by Winrock International to the California Energy Commission - PIER Energy-Related Environmental Research [publication 500-04-068F]). Additional data and methodologies that have become available since the publication of that report have made it possible to refine and extend the analysis of hazardous fuel reduction in California.

The general approach to the analysis of carbon supply for different activities is to estimate the total quantity of carbon that could be sequestered through changes in use and management of lands, along with the total costs of these changes. Hazardous fuel reduction is analyzed as a potential activity to reduce greenhouse gas emissions and preserve forest carbon stocks. We estimate the area of California forests at high and very high risk of fire; assign Suitability for Potential Fuel Reduction (SPFR) scores to these lands, ranking lands for treatment based on criteria of slope, distance from roads, and distance from biomass energy facilities; and analyze area treated, biomass yield, and economics of one typical fuel reduction treatment.

Keywords: carbon sequestration, forest management, hazardous fuel reduction

Executive Summary

Introduction

This report serves as an update to the earlier analyses sponsored by EPRI and the California Energy Commission (Brown et al. 2004, Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California, report by Winrock International to the California Energy Commission - PIER Energy-Related Environmental Research [publication 500-04-068F]). Additional data and methodologies that have become available since the publication of that report have made it possible to refine the analysis of hazardous fuel reduction in California (Chapter 1, Section 5 of the Brown et al. 2004 report).

Purpose

The broad purpose of the project entitled "BASELINES, CARBON SUPPLY CURVES AND PILOT ACTIONS FOR TERRESTRIAL CARBON SEQUESTRATION" is to quantify terrestrial carbon sequestration opportunities across the West Coast Partnership Region (Arizona, California, Oregon, and Washington) and estimate the quantity of carbon credits that might be available at different price points.

Project Objectives

The four primary objectives of this study are:

- Revise as needed the areas of forestland in California with high to very high fire risk.
- Conduct a multi-criteria evaluation to identify forestlands suitable for fuel removal. This analysis assigns a "Suitability for Potential Fuel Reduction (SPFR)" score to all forested areas, based on criteria affecting the feasibility of treating these lands, removing and transporting fuels for biomass energy generation.
- Conduct more detailed analysis of one potential hazardous fuel removal (HFR) treatment, CSCH, and assess the area of high to very high fire risk forestlands in the state to which this treatment could be applied, how much biomass fuel this might generate for use in power plants, and at what cost.
- Identify areas of low-elevation ponderosa pine and mid-elevation mixed coniferous forests that could be treated for fuel reduction with CSCH to mitigate potential extreme fire behavior and restore these forests to their historical fire regime.

Project Outcomes

The hazardous fuel reduction analysis found that the area of California forests at high to very high risk of fire is approximately 16.2 million acres. A commonly used potential hazardous fuels treatment is "Cut-Skid-Chip-Haul" (CSCH), a treatment in which hazardous fuel is harvested in the woods, bunched and skidded to a landing, chipped into a chip van, and hauled to a biomass energy facility for electricity and/or heat generation. The area of high to very high fire risk forestlands in the state to which this treatment could be applied (on lands with <40% slope, within 400 meters of existing roads, and within 50 miles of biomass energy facility) is approximately 2.2 million acres (14% of the total) containing an estimated biomass stocking, including trees, of 81 MMT C. Two removal scenarios were analyzed: HFR removal of 4 bone dry tons (BDT)/ac on these lands would yield 9.1 million BDT biomass fuel for use in energy facilities, while removal of 8 BDT/acre would yield 18.1 million BDT. Total estimated costs and potential revenue from these removals was analyzed, with the finding that treating these 2.2 million acres of high to very high fire risk forestlands considered accessible for CSCH would range from generating a net revenue of $18 million to requiring a total subsidy of $109 million (with 4 BDT/acre removal) or generating a net revenue of $36 million to requiring a total subsidy of $218 million (with 8 BDT/acre removal).

During moderate to intense fires, 10-70% of the biomass stock burns and is emitted as CO_2. Applying this range to the forests suitable for treatment with CSCH, and assuming the fuel removal prevents hazardous fires, has the potential to reduce emissions by 30-208 MMT CO_2. A preliminary analysis suggested that considering the differences in CO_2 emissions between high-, medium- and low-intensity fires, HFR treatments that reduced fire intensity would avoid sufficient emissions to be able to cover, at commonly used prices for carbon of \$2.40/t CO_2 and \$10/t CO_2, the subsidies needed to pay for CSCH – adding support to the argument for qualifying fuel reduction activities as carbon offset projects. This preliminary analysis needs further research on baseline emissions from wildfires of varying severity, as well as policy discussion on what reductions in fire severity and/or emissions can be considered attributable to HFR treatment.

Conclusions

This update of the hazardous fuels reduction section of the original California carbon supply report (Brown et al. 2004) shows that:

- About 16.2 million acres of California forests, containing about 664 million tons of carbon, are at high to very high risk of fire.
- Approximately 2.2 million acres of forests containing an estimated biomass stocking of 81 MMT C could be treated with the CSCH treatment method.
- Assuming about 10-70% of the biomass stock burns and is emitted as CO_2 during a fire, fuel removal has the potential to reduce emissions by 30-208 MMT CO_2.
- Reduced emissions from wildfire attributable to hazardous fuel reduction, when valued at commonly used prices for CO_2, are on the same order of magnitude as the emissions reductions that would be needed to pay for currently uneconomic HFR treatments.

Recommendations

Further characterization work is needed to refine the analyses done to date and to evaluate additional carbon sequestration opportunities for the state and region. It is recommended that further work focus in particular on refinements to the analysis of fuel load reduction on wildfire-prone forests. Recommended next steps include the analysis of other fuel removal treatment types and how the constraints on each affect the amount of forest land that could be treated; and the development of baselines for various wildfire-prone forest types. These baselines will serve as the reference case against which activities to reduce fires would be compared to estimate the potential carbon credits. Such baselines need to include field data and models to quantify the likelihood of fires occurring (e.g. fire-return interval) as well as the effects of fire on greenhouse gas emissions from forests under different intensities of fire (how much of the forest's carbon stock in different pools is emitted under different fire intensities and stand structures). More detailed economic analysis is also needed to determine if fuel removal produces sufficient emissions reductions to pay for currently uneconomic treatments.

5 Forest Fuel Reduction

5.1 Introduction

Fire occurrence has a significant effect on the amount of carbon in California's forested areas (EPRI 2004). Fire management techniques that reduce carbon emissions by reducing the risk, severity, or extent of wildfires through removal of biomass fuels potentially offer an opportunity to supply carbon credits. Not only would reductions in catastrophic forest fires reduce carbon and non-CO_2 GHG emissions from burning, but the use of the biomass to generate electricity would also offset emissions from fossil fuel-generated electricity. The overall objective of this section is to produce a first-order approximation of the areas and carbon stocks of forests suitable for fuel reduction to reduce their fire risk and their location relative to existing power plants.

5.1.1 Magnitude of the problem

The last century has seen the transformation of many western forest ecosystems from relatively open, healthy forests in which periodic low-intensity ground fire played an important ecosystem function, to densely stocked, fire-prone forests in which catastrophic crown fires burn hundreds of thousands of acres each fire season. This has resulted in escalating fire suppression budgets, loss of timber, wildlife, recreational and ecosystem values, lost property values, skyrocketing insurance costs, and loss of life. Fires appear to be increasing in size and intensity during the last decade, resulting in amplified loss of carbon stocks and billions of tax dollars spent each year towards control efforts (Figure 5-1). As reported by the National Interagency Fire Center, 103,387 fires consumed 4.5 million acres in 1960; by the year 2000, 122,827 fires burned almost twice as much—8.4 million acres—while federal expenditures rose from $845 million in 1994 to $1.7 billion in 2002 (NIFC 2003) (Figure 5-2).

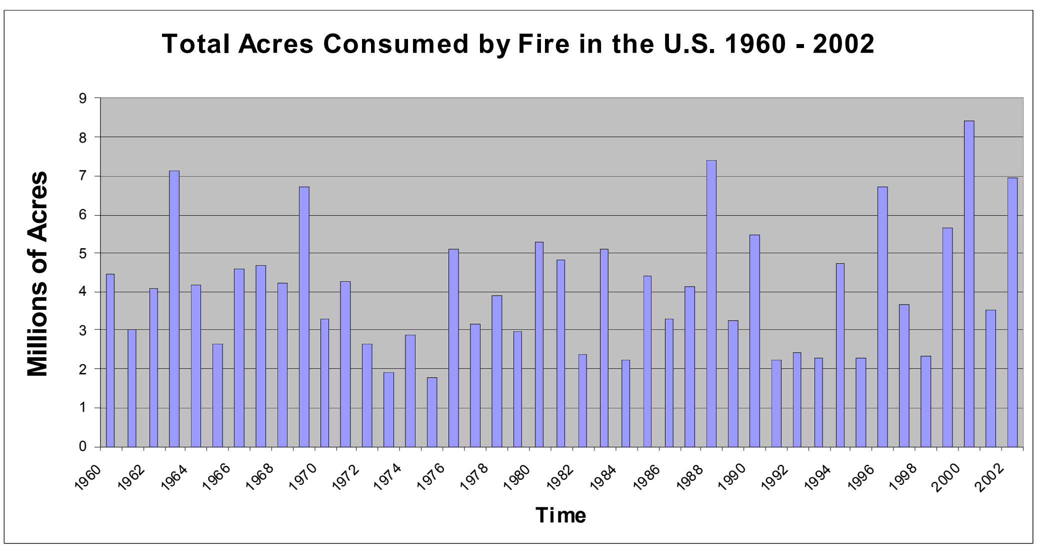

Figure 5-1. National Interagency Fire Statistics showing the area burned by wildfires in the U.S. from 1960 to 2002.

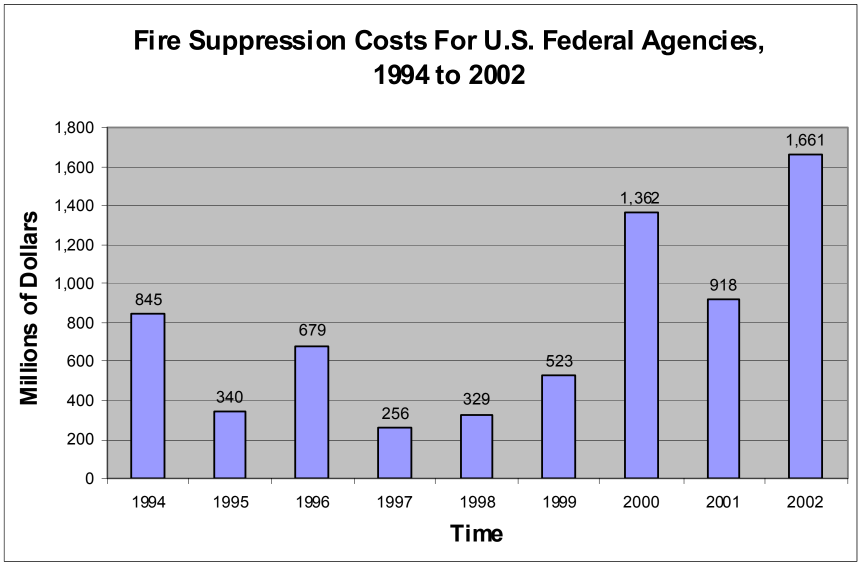

Figure 5-2. National Interagency Fire Center statistics showing federal expenditures in millions of dollars from 1994 to 2002.

The USDA Forest Service (USFS) in 1937 adopted policy of "fast, energetic and thorough suppression of all fires in all locations" (Chase 1989). A more recent scientific consensus suggests that low-intensity ground fire played a natural and important role in many Western forest ecosystems (e.g. Schoennagel et al., 2004). Instead of having a healthy fire return interval of 15 or 20 years depending on forest type, a combination of logging, fire suppression and other factors have altered fire regimes and resulted in a fundamentally different forest landscape in which accumulated woody fuels create conditions for infrequent but intense and large-scale fires that can permanently alter ecosystems (Pyne et al 1996). This has led to a debate among landowners and public land managers about how to manage fire across boundaries, and how to return natural low-intensity fire to these forest ecosystems, starting from a present condition of accumulated fuels that makes it impossible simply to forego fire suppression, let fires burn, or introduce prescribed fire without first undertaking treatments to reduce fuel loads. A national consensus is beginning to develop among government, industry, community and environmental stakeholders that something must be done to reduce fuel loads and return forests to more natural fire regimes; nonetheless, the problem is complex and the barriers to a large-scale solution are political, administrative, environmental, and perhaps most significantly economic. The necessary fuel reduction treatments tend to be labor-intensive and very costly, the value of the material removed relatively low, and agency budgets to pay for treatment increasingly constrained. Creative utilization strategies for understory biomass and small-diameter timber are needed, together with a broad portfolio of approaches and sources of revenue to offset the costs of fuel treatment.

A recent assessment of forests across 15 Western states, conducted under the auspices of the National Fire Plan, found that approximately 67 million acres are at high to very high risk of wildfire (Fire Regime Condition Class 2 and 3) and 28 million acres at the highest risk level

(FRCC 3).[2] These figures include only those acres considered accessible for some type of treatment to reduce hazardous fuels. The 28 million acres in FRCC 3 could yield 345 million bone dry tons (BDT) in removals, with the greater proportion (70%) of the volume in larger diameter classes (over 7″ considered merchantable sawtimber), but the greater number of stems in the < 7″ submerchantable biomass category (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003). This hints at both the scale of the wildfire risk/hazardous fuels problem in the West, and one of the key economic barriers: a huge quantity of submerchantable material requiring treatment and/or removal to reduce fire risk, but constituting relatively little volume or value to pay the high cost of handling such a large number of stems.

In California alone, 11.8 million acres in FRCC 2 and 3 require hazardous fuel reduction and would yield an estimated 318 million BDT, of which 5.5 million acres are in FRCC 3 and would yield an estimated 125 million BDT (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003).

A recent study conducted by the University of California, Davis developed a GIS tool with the objective of estimating supply curves for forest thinnings and residues to biomass facilities by (1) reducing uncertainty in the amounts of available biomass at specific locations over the range of delivered price, making development of new energy plants more attractive, (2) escalating use of forest biomass for energy while expanding employment in rural forest areas, (3) moderating adverse effects of not using biomass for energy caused by stand-replacing wildland fires, and (4) reducing cost of energy produced from forest biomass through available GIS technologies to locate suitable areas for new power plants (Chalmers et al. 2003). This study however covered only one county (Plumas), and did not examine the potential economic benefits of using alternatives to fossil fuels for producing electricity.

5.1.2 Approach and analysis of hazardous fuel reduction treatments

A range of potential hazardous fuel reduction (HFR) treatments and technologies is available to address the fire risk problem. Prescribed fire is a relatively low-cost way to reduce fuel loading and ultimately perhaps the preferred treatment if the goal is to reintroduce fire into forest ecosystems. Prescribed fire is fairly constrained in its use today, however, because of the potential for fire escape (especially at the wildland-urban interface), relatively short windows of appropriate conditions, and air quality and sediment yield concerns. Indeed, to treat FRCC 3 forest lands, prescribed fire is probably an option only following some mechanical treatment to reduce fuel loads (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003). One could envision a range of available HFR treatments, each with different

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[2] Fire Regime Condition Class (FRCC) is a measure of how much a forest has departed from natural wildland fire conditions (Schmidt et al 2002). The fire regime in Class 2 areas is moderately altered from the historical range; moderate levels of restoration treatments such as fire or mechanical treatments would be required to begin managing a more natural fire cycle. In Class 3 areas, fire regimes have been significantly altered and there is a high risk of losing key ecosystem components in a wildfire. Due to high fuel loadings, mechanical treatments are expected to be needed before the reintroduction of fire (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003).

constraints, costs, yield of merchantable and submerchantable material and thus revenues, air quality impacts, ground impacts, and greenhouse gas emission impacts (Figure 5-3, Table 5-1).

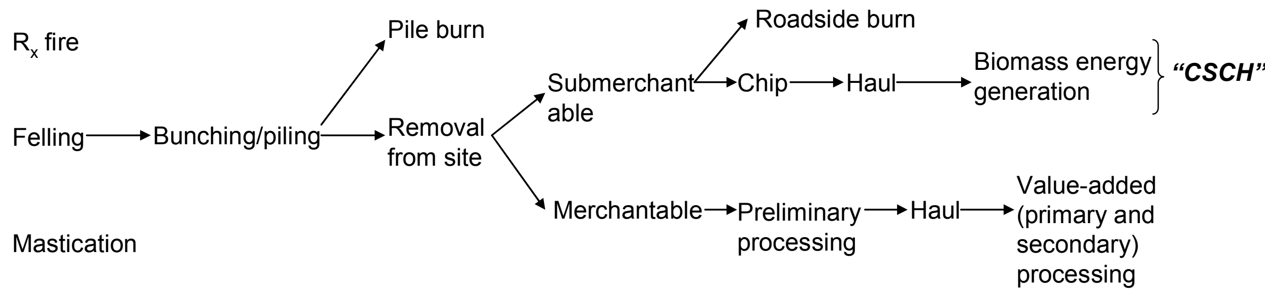

Figure 5-3. Schematic of potential HFR treatments (adapted from USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003).

Table 5-1. Benefits, constraints and representative costs for HFR treatments.

Hazardous fuels reduction treatment	**Product yield**	**Benefits**	**Constraints**	**Representative costs**
R_x fire	No	Less expensive, re-introduces fire	Air quality, ground impacts, fire escape (WUI), seasonal restrictions, immediate CO_2 emissions to atmosphere	\$35-300/acre, average \$92/acre[3] \$23-223/acre[4]
Masticate – leave on site	No	Efficient, useful for less accessible sites where fuel removal not a goal	Leaves fuel on site, gradual CO_2 emissions to atmosphere	\$100-1,000/acre[2]
Cut-pile-burn	No	Less expensive, can be used on inaccessible or steep sites	Leaves fuel on site, air quality, immediate CO_2 emissions to atmosphere	\$100-750/acre[2]
Cut-lop-scatter	No	Less expensive, can be used on	Leaves fuel on site, gradual CO_2 emissions	\$105-280/acre[5]

[3] USDA Forest Service Research & Development/Western Forestry Leadership Coalition, 2003.

[4] Chalmers and Hartsough, no date.

		inaccessible or steep sites	to atmosphere	
Cable yarding for biomass removal	Yes	Makes less accessible or steeper sites treatable	Expensive, ground impacts	\$80-130/CCF[4]
Cut-skid-chip-haul (for submerchantable biomass) ***"CSCH"***	Yes	Removes fuel from site; some product value to offset costs; allows renewable energy generation; greatest CO_2 benefit	More expensive; limited to gentler slopes, areas closer to roads for removal, limited haul distance to biomass plant	\$34-48/BDT + haul cost \$0.35/BDT.mile[1] \$560-1,634/acre[6]
Cut-skid-process-load-haul (for merchantable)	Yes	Greatest product value to offset costs; removal of merchantable material may be necessary to reduce fire risk (Crowning Index) and meet spacing or forest health goals	More expensive; limited to gentler slopes, areas closer to roads for removal, limited haul distance to processing facility; environmental controversy/frequent litigation	Variable

The present analysis is confined to a single HFR treatment – cut-skid-chip-haul, or "CSCH" – because this appears to be the practical way to reduce fuel loading in the forest while at the same yielding some biomass fuel for transportation to biomass energy power plants (thus some value to offset treatment costs). We attempt to estimate the total area of California forest lands at high and very high fire risk, how much of this area meets a series of constraints making it feasible to treat using CSCH, how much biomass could be removed from this area using CSCH, and what might be the economics of using CSCH on those forested acres. Thus the focus is primarily on submerchantable biomass, and the use of forest fuels for generating heat and power in biomass energy facilities.

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[5] Fight et al. 2004, Barbour et al 2004.

[6] Fried et al 2003.

This approach is necessarily a simplification of the reality of HFR as practiced today, in which a variety of treatments can be applied for different locations, terrain, slope or other conditions. Perhaps most importantly, most HFR prescriptions call for a mix of submerchantable and merchantable material removal, both for economic reasons and to target a desired future forest condition that is defined in terms of residual spacing or basal area, residual fuel loading, reduced ladder fuels to prevent ground fires from moving into the crown, and reduced crown density or crown-touching to prevent crown fires from being sustained or spreading over long distances (Fried et al 2003). While diameter limits are sometimes applied, it is rarely appropriate to exclude all merchantable material to meet these desired future conditions. Accordingly, different treatment types, technologies, and product yield mean different economics of HFR and different types of sites that become treatable either in technical terms (e.g. treatments available for steep slopes) or in economic terms (e.g. treatments that yield more merchantable material, offsetting costs and allowing the contractor to remove more submerchantable biomass to reduce ladder fuels, or treat lands on the margin of the maximum haul distance from a biomass energy facility). There is a large literature focused on the economics of different treatments, models to estimate costs of treatment (STHARVEST and others), and models to estimate quantities of biomass available from a given area or the best locations to site biomass energy facilities (FIA Biosum, Coordinated Resource Offering Protocol, and others) (Fight et al 2003, 2004; Fried, Barbour and Fight 2003; Fried et al 2002, 2003; Barbour et al 2001, 2004; Christensen et al 2002; Chalmers and Hartsough, no date; Mater 2005).

Confining the analysis to CSCH, the area treated and biomass yield associated with this approach results in conservative estimates. Additional area would become economically treatable if merchantable material were included in the analysis; additional area would become technically treatable if other treatment types, not attempting to remove biomass but still reducing fuel loads (e.g. cut-pile-burn for steep slopes) were considered. These refinements will be addressed in later analyses.

5.1.3 Objectives

The four primary objectives of this study are:

1) Identify areas of forestland in California with high to very high fire risk.
2) Conduct a multi-criteria evaluation to identify forestlands suitable for fuel removal. This analysis assigns a "Suitability for Potential Fuel Reduction (SPFR)" score to all forested areas, based on criteria affecting the feasibility of treating these lands, removing and transporting fuels for biomass energy generation.
3) Conduct more detailed analysis of one potential HFR treatment, CSCH, and assess the area of high to very high fire risk forestlands in the state to which this treatment could be applied, how much biomass fuel this might generate for use in power plants, and at what cost.
4) Identify areas of low-elevation ponderosa pine and mid-elevation mixed coniferous forests that could be treated for fuel reduction with CSCH to mitigate potential extreme fire behavior and restore these forests to their historical fire regime.

5.2 Results: forested land at high to very high fire risk

The first step of the analysis was to locate forested areas at high to very high risk of stand-replacing wildland fire. A CDF-FRAP 2002 land-cover map was used to extract forested areas, creating a new layer called "forest" that was then combined with a second FRAP fuel rank layer and used as a mask to identify forested areas at high and very high fire risk. The FRAP fuel rank layer was derived using detailed surface fuel layers and information based on quantities of ladder and crown fuels (CDF-FRAP 2004).[7] Non-fuel and moderate fuel rank classes were left out of the analysis. The high and very high fuel rank attributes were combined with the "forest" layer to create a new layer, "high risk forest" (Figure 5-4). The total area of California forests designated as high or very high risk of wildfire is **about 6.6 million hectares**.

[7] For additional information on the land cover/fire data and methods, refer to the metadata downloadable from the FRAP website, http://frap.cdf.ca.gov/data/frapgisdata/select.asp.

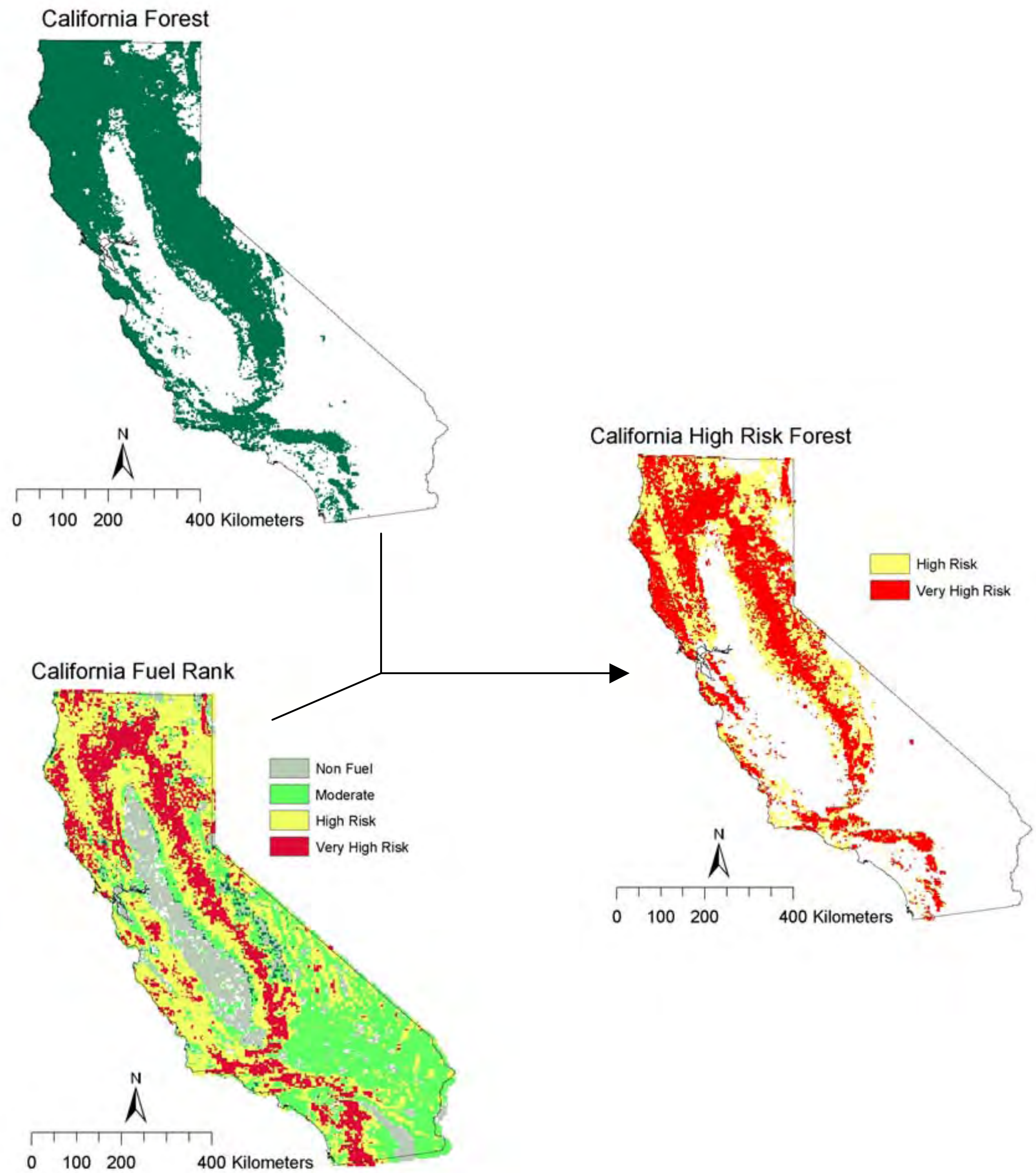

Figure 5-4. Distribution of California's forests at high and very high risk for catastrophic fire.

5.3 Results: suitability for potential fuel reduction

A multi-criteria evaluation (MCE) was conducted to identify forestlands suitable for fuel removal. Three factor maps were used in the decision support tool for a Multi-Criteria Evaluation module (Eastman 2003): distance from roads, distance from power plants, and slope. The analysis was constrained to a radius of 50 miles from existing power plants, representing a general rule-of-thumb for maximum hauling distance for low-value biomass fuel. These factor maps were combined to create a single raster map showing Suitability for Potential Fuel Removal (SPFR) scores.

The first factor analyzed was distance from roads. Six transportation-related shapefiles (local_roads, railroads, state_highways, thoroughfare2, us_highways, and vehicular_trails) were downloaded from the CASIL website and merged into one file called "all_roads" (CASIL 2004). A straight-line Euclidean distance operator was applied to the roads layer and standardized using a fuzzy soft classifier for use in the MCE. California state law requires that all fuels within 100 meters of a roadway must be removed to reduce risk of fire (CDF 2003). Therefore the starting point for most suitable areas began 100 meters from existing roads and became less suitable as distance from roads increased (Figure 5-5).

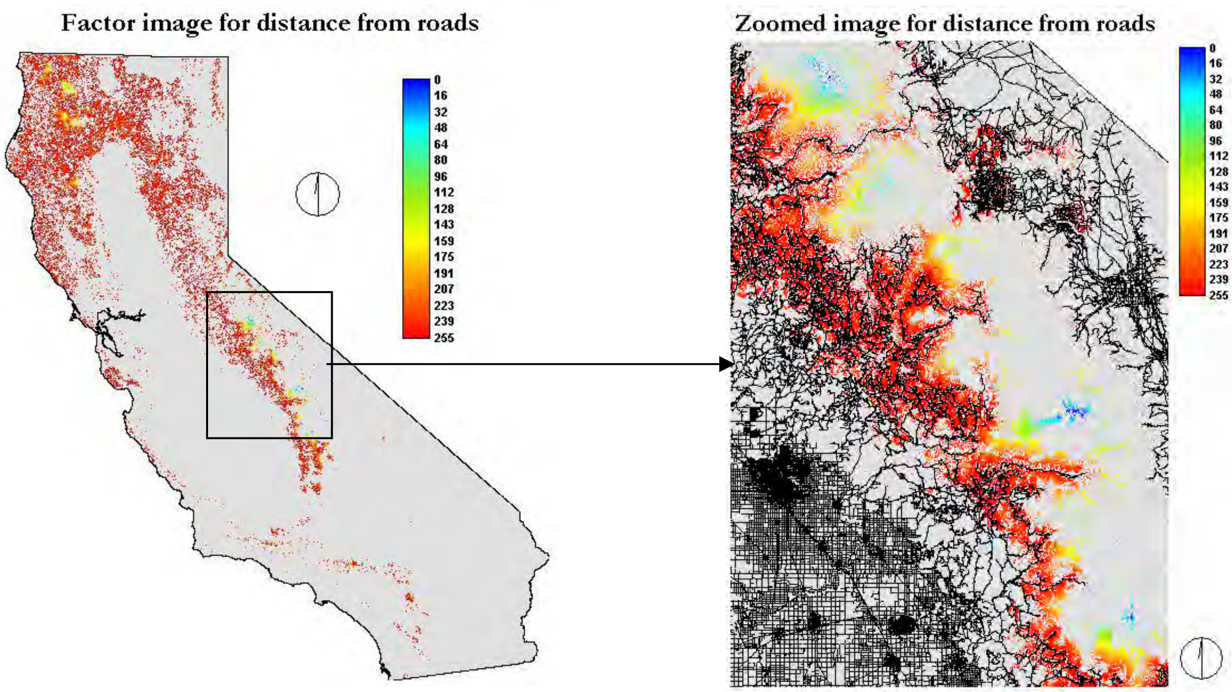

Figure 5-5. Factor image for distance from roads used in the MCE on a scale of 0 to 255, where 0 is the least suitable (furthest from roads) and 255 is the most suitable (closest to roads). The zoomed image shows greater detail on the map.

The second factor analyzed was slope. A slope image was created using a Digital Elevation Model (DEM) acquired from the CASIL web site and masked to the high and very high risk forest areas. The original slope map was in units of degrees but was standardized with a fuzzy soft classifier to give it a range of suitability between 0 and 255, with 255 representing the gentlest slope (easiest access and least ground impact from fuel removal, thus most suitable) and 0 the steepest slope (least suitable) (Figure 5-6).

The third factor analyzed was distance from existing biomass power plants. An Excel file with locations of operational biomass power plants in California producing 0.1MW and above was provided by the California Energy Commission (CEC). The Excel file included fields for X and

Y coordinates which were used to create a point file and added to the analysis maps. As with the distance from roads factor, a straight-line Euclidean distance operator was applied to the locations of biomass plants and standardized with values of 0 to 255, with the greatest travel distance to reach a power plant assigned the lowest suitability score and the least travel distance the highest suitability score, indicating that as the distance to the nearest power plant increases, cost of hauling fuel increases and suitability for fuel removal thus decreases (Figure 5-7).

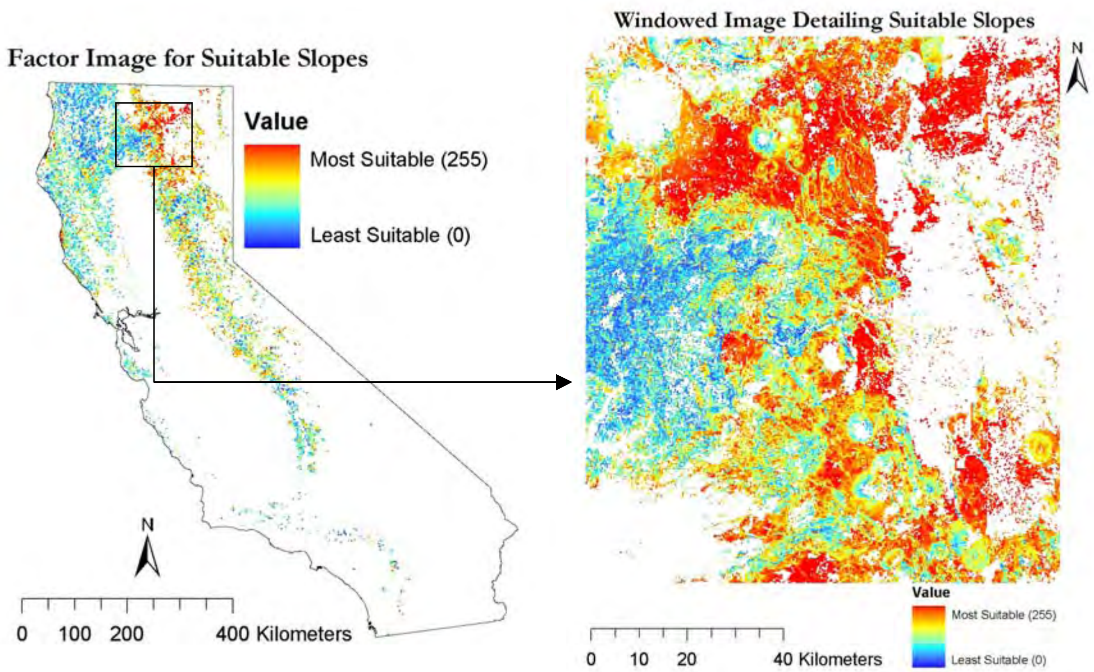

Figure 5-6. Slope suitability factor map and zoomed image detailing suitable slopes, where 0 is the least suitable (steepest slopes) and 255 is the most suitable (gentlest slopes).

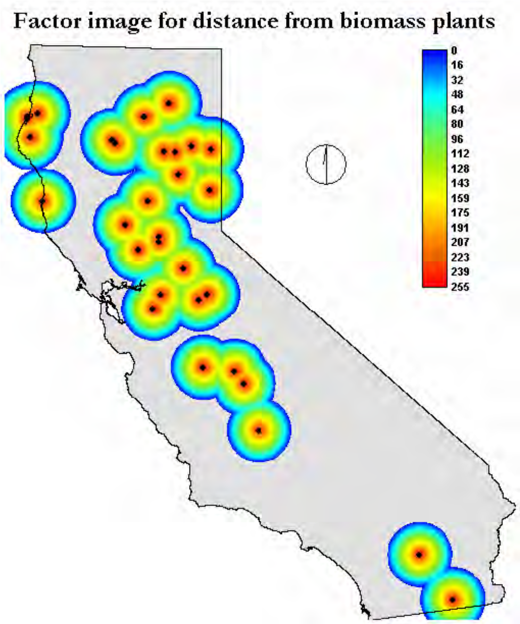

Figure 5-7. Suitability map showing distance from biomass plants, where the highest suitability scores are assigned to areas close to existing plants.

All three factor maps were used as inputs for the MCE module, a GIS decision making tool in Idrisi Kilimanjaro software (Eastman 2003). The output of this module was a SPFR score map on a standard scale from 0 to 255, where 0 represents the least suitable areas and 255 the most suitable areas for fuel reduction accounting for distance to roads, slope and distance to power plants (Figure 5-8).

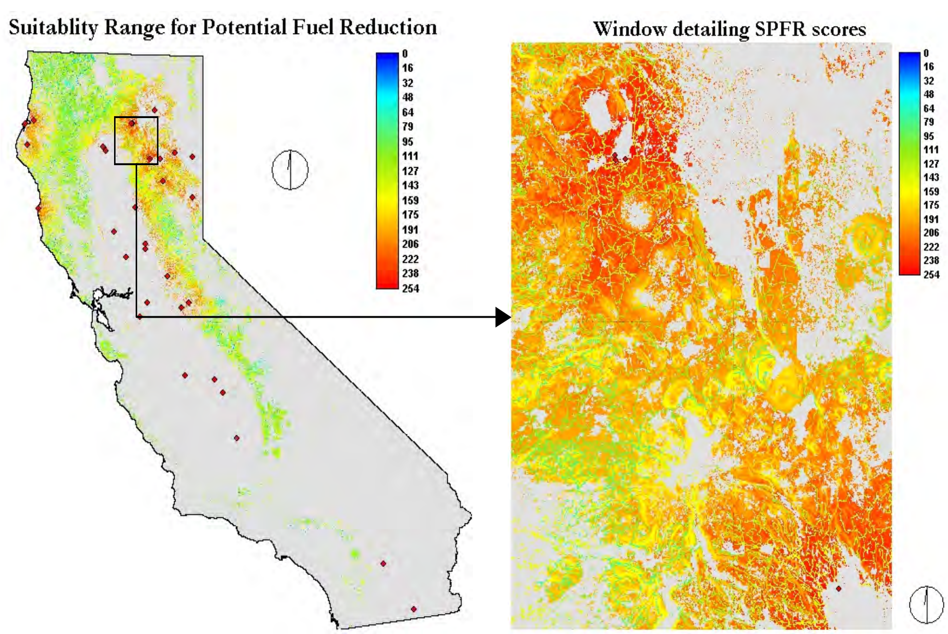

Figure 5-8. SPFR scores for California forests, with highest suitability assigned to areas with gentle slope, close to roads and close to existing biomass power plants.

The forest types that dominate in different ranges of SPFR scores were then examined. A histogram of the area of forests in the final SPFR map shows that there are few forests in the low classes (less than 94), with the area increasing rapidly between 100 to 130 classes, then gradually declining through the rest of the classes (Figure 5-9).

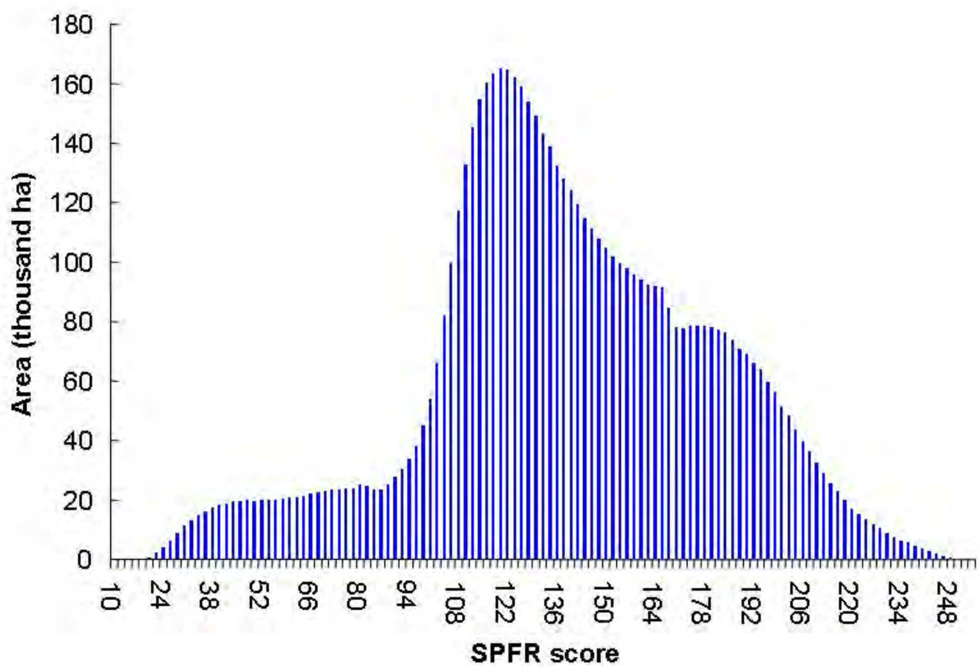

Figure 5-9. Area of forests at very high and high risk in each SPFR class.

Across the state, the vegetation composition of these SPFR classes is dominated by 'Other Conifer Forest' and 'Hardwood Forest,' with some 'Fir-Spruce Forest,' 'Redwood Forest' and 'Douglas Fir Forest' that decline in proportion to the others as SPFR scores increase (Figure 5-10). The 'Other Conifer' class is expected, as this class is composed mostly of the pines that grow in highly fire-prone areas and are some of the most fire resistant forests in California.

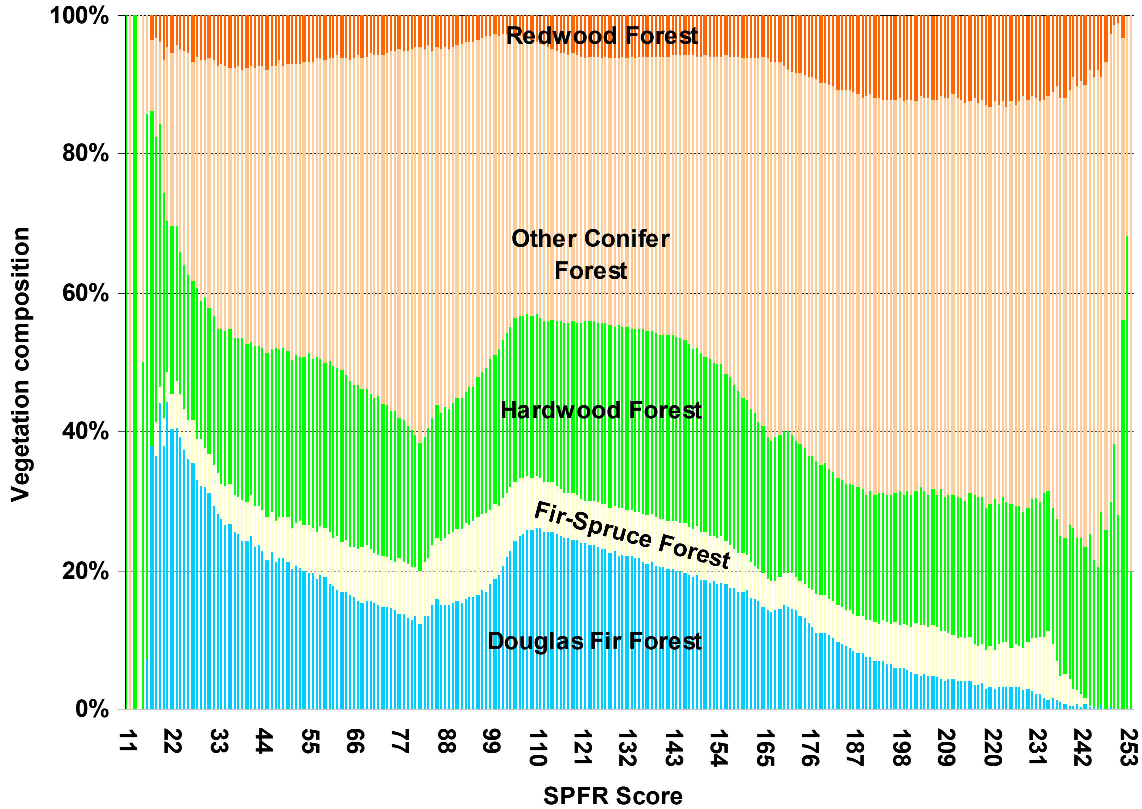

Figure 5-10. Forest composition across SPFR classes for areas at high and very high risk of fire.

To estimate the carbon stocks at risk of being lost (emitted to the atmosphere) through wildland fire, baseline carbon stocks were estimated. The CDF-FRAP Multi-Source Land-cover Map that was used in the analysis contains attribute information for all 'WHR' (Wildlife Habitat Relationship) land-cover classes mapped. In a parallel Winrock International study on baseline carbon emissions in California (EPRI 2004), a methodology was developed to estimate carbon stocks using the forest type and canopy cover class attributes. Using this study, carbon stocks were estimated for each canopy class and re-grouped WHR classes. This matrix of carbon stock estimates was used with the re-classed WHR map to assign a carbon stock to each pixel. In areas where no information was given in the 'WHR-density' (canopy density) field, the value was conservatively estimated to be the lowest percent canopy-cover. Baseline carbon stocks for California high and very high fire risk forests across the range of SPFR classes are shown in Figure 5-11. The total carbon stocks for these high and very high fire risk forests were estimated to be **about 664 million t C**.

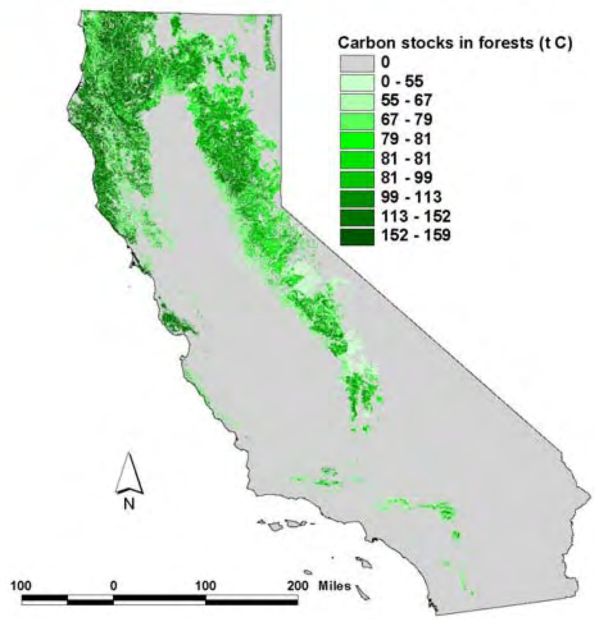

Figure 5-11. Map of carbon stocks for California forests.

The carbon stocks map was superimposed on the SPFR map to estimate the quantity of carbon in forests across different SPFR scores. The carbon stocks that the model identifies as being at risk for wildfire for each level of SPFR are shown in Figure 5-12**.**

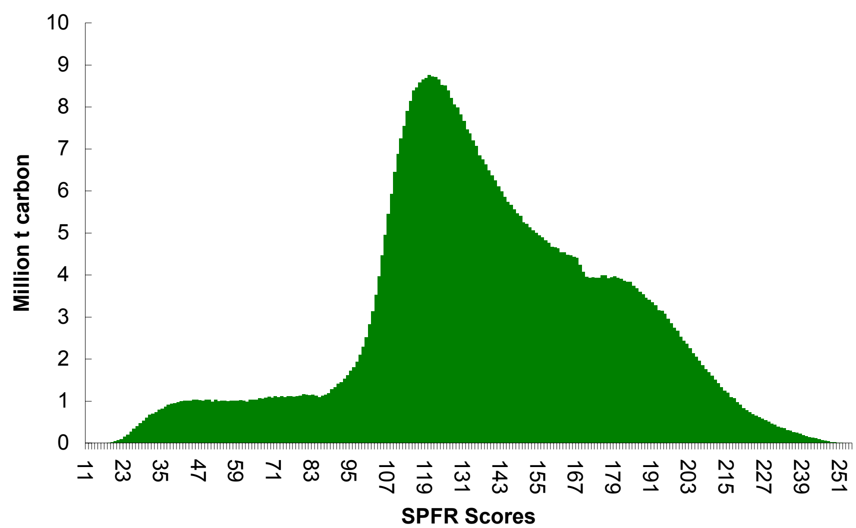

Figure 5-12. Carbon stocks by SPFR classes for forests at high and very high risk for fire.

5.4 Results: high to very high risk forests treatable with "CSCH"

5.4.1 Estimated biomass yield

In the third component of this analysis, we looked in more detail at one potential hazardous fuels treatment, "Cut-Skid-Chip-Haul" (CSCH), a treatment in which hazardous fuel is harvested in the woods, bunched and skidded to a landing, chipped into a chip van, and hauled to a biomass energy facility for electricity and/or heat generation. The objective was to assess the area of high to very high fire risk forestlands in the state to which this treatment could be applied, how much biomass fuel this might generate for use in power plants, and at what cost.

This analysis used the following crucial constraints on the feasibility of CSCH treatment:

- Maximum slope constraint. Only lands of < 40% slope may be treated with CSCH (Fight et al 2003; Fried et al 2002; Fried et al 2003; Fried, Barbour and Fight 2003). Steeper slopes may be treated in other ways (e.g. cut-pile-burn), but do not allow CSCH due to machinery and equipment access, ease of removal, and ground impacts from harvest and skidding.
- Maximum yarding distance constraint. Only lands within 0.25 miles (400 meters) of existing roads may be treated with CSCH. This is used as a general rule of thumb for the maximum distance low-value material would be skidded to a landing where a chipper and chip van is parked (Bob Rynearson, WM Beaty & Associates, pers comm. September 2005).
- Maximum haul distance constraint. As above, only lands within 50 miles of existing power plants may be treated with CSCH due to transport cost. This maximum haul distance may be considerably affected by the volume/value of merchantable material in the prescription, but for a simplified CSCH treatment targeting only low-value submerchantable material, it is assumed that haul distance cannot exceed 50 miles.
- Minimum block size to justify move-in costs of equipment and personnel. A general rule of thumb is that a treatment block must be at least 80-100 acres to justify move-in costs, although this number may be slightly less if equipment is already sited nearby for another project (Bob Rynearson, WM Beaty & Associates, pers comm. September 2005).

Initially, we applied only the first three constraints in order to generate results for comparison to similar analyses for Oregon and Washington, in which it was impossible to apply the constraint of minimum block size due to a relatively coarse level of resolution of 1,000m per pixel (one pixel = 247 acres). The first three constraints were applied sequentially so that only lands meeting all constraints were available for CSCH treatment. Forests at high and very high wildfire risk were superimposed on a slope map and all forestlands of > 40 % slope were excluded (Figure 5-13 A). To meet the requirement of maximum 0.25 miles yarding distance, a buffer layer was created, rasterized and overlaid with the high and very high fire risk forest on gentle slopes to exclude any lands further than 0.25 miles from roads (Figure 5-13 B). The constraint map of 50 mile radii from existing power plants was overlaid on the earlier maps to exclude forests beyond this haul distance (Figure 5-13 C).

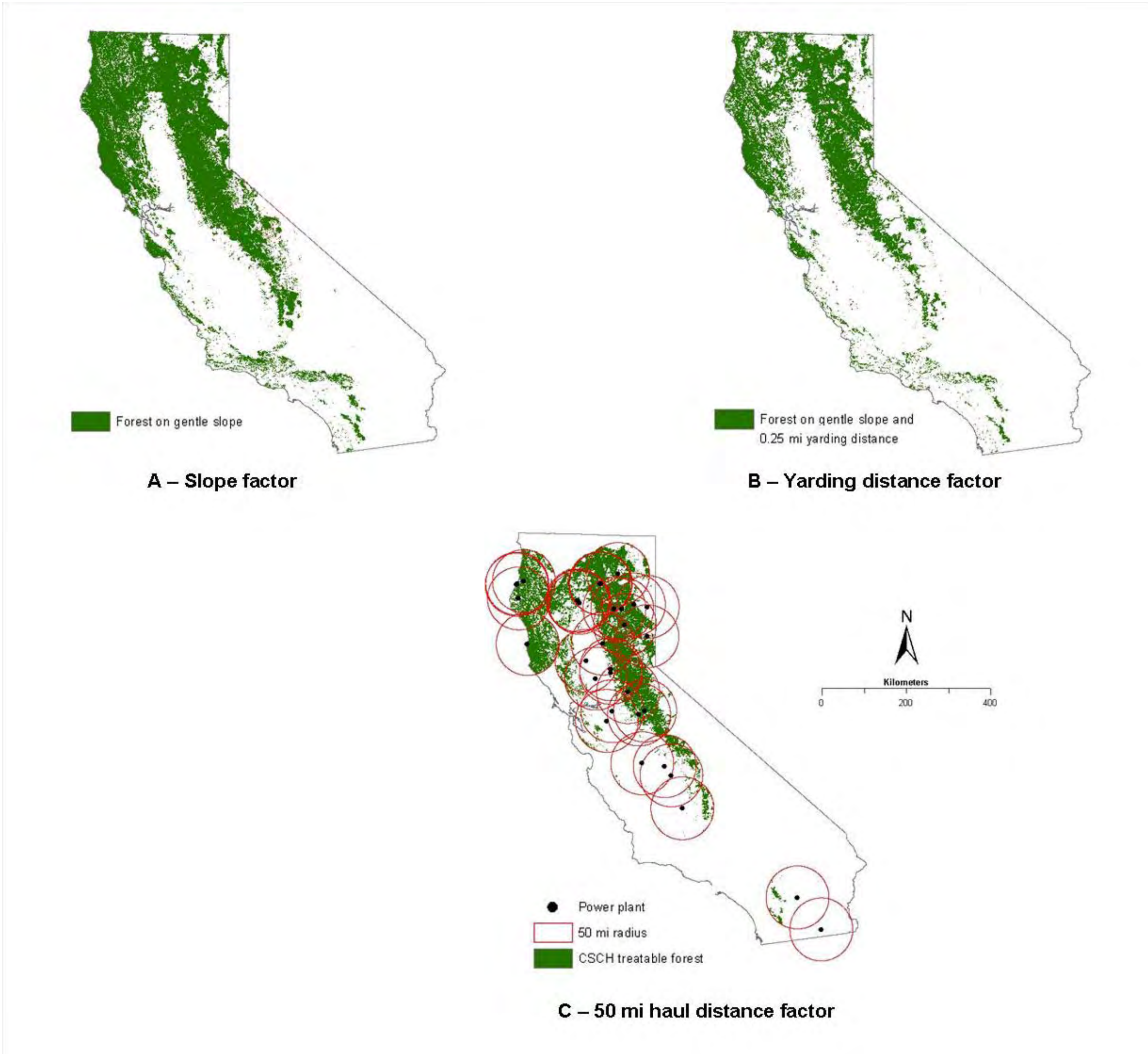

Figure 5-13. Critical factors to determine forest lands suitable for CSCH fuel treatment: A - Slope less than 40%; B - Yarding distance less than 0.25mi; C- Distance from existing power plants less than 50 miles.

Considering only lands meeting all three constraints, the total area accessible for CSCH across California high and very high fire risk forest lands would be approximately **907 thousand hectares**, or approximately 14% of the total area of high and very high fire risk forest**.**

The total fuel available from these 907 thousand hectares would depend on the proportion of the total biomass stocking removed in a HFR treatment. Actual percent removal in HFR prescriptions is highly variable by stand, pre-treatment condition and desired future condition (D. Goehring and D. McCall, PG&E Natural Resources, pers comm. September 2005), making it difficult to assign a percent removal across a broad scale such as a state or region. Over the landscape as a whole, more than 50% removal of the pre-treatment fuel loading may be needed to significantly reduce fire risk (Torching Index and/or Crowning Index; Fried et al. 2002, 2003).

Furthermore, more than 50% removal, as a landscape average, is likely to be needed to reach a stand-level residual basal area of 80-125 ft^2/acre, often used in HFR prescription scenarios (Fried et al. 2002). A 15-state strategic assessment of fuels reduction assumed a removal prescription of reducing stand density to 30% of maximum Stand Density Index (SDI) for a given stand, or averaged across the landscape, 70% reduction in SDI (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003).

Given the uncertainty in fuel available for removal, two scenarios were considered to help understand the relationship between potential fuel removal and the subsequent carbon benefits associated with that removal. The first scenario assumed that regardless of pre-treatment condition and desired future condition of the forest stand, CSCH treatment will remove 10 BDT biomass per hectare (4 BDT/ac). The second scenario assumed that 20 BDT biomass per hectare (8 BDT/ac) will be removed. In the first scenario, biomass of **approximately 9.1 million BDT** would be available to biomass energy facilities in California from CSCH treatments on high to very high fire risk forest lands. This implies an initial loss of forest carbon due to HFR treatment of approximately 4.6 million t C [8] -- although this initial loss is obviously offset by potentially great savings in CO_2 and non-CO_2 greenhouse gas emissions due to reduction in the probability, severity and extent of wildfire attributable to the HFR treatment. The second scenario results in **approximately 18.1 million BDT** available biomass associated with approximately 9.1 million t C initial removals. The total carbon stocks for these California forests at high and very high risk of wildfire, feasible for CSCH treatment, are **approximately 81 million t C**.

Higher-resolution data available for California in fact make it possible to apply the fourth constraint of minimum block size to justify move-in costs. When this constraint is added, excluding lands that meet the first three constraints but with contiguous area of less than 80 acres (Figure 5-14 D), the above results change as follows:

- The total area of California high and very high fire risk forest lands accessible for CSCH (meeting all four constraints) is approximately **613 thousand hectares**, or approximately 9% of the total area of high and very high fire risk forest**;**
- In the first scenario, with removal of 10 BDT/ha, treating these lands would yield **approximately 6 million BDT** of biomass fuel for biomass energy facilities, with an associated initial loss of forest carbon of 3 million t C. In the second scenario, with removal of 20 BDT/ha, the biomass yield would be **approximately 12 million BDT** associated with 6 million t C initial removals. The total carbon stocks for these California forests at high and very high risk of wildfire, feasible for CSCH treatment, are approximately 54 million t C.

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8 Carbon stocks are calculated as 50% of biomass.

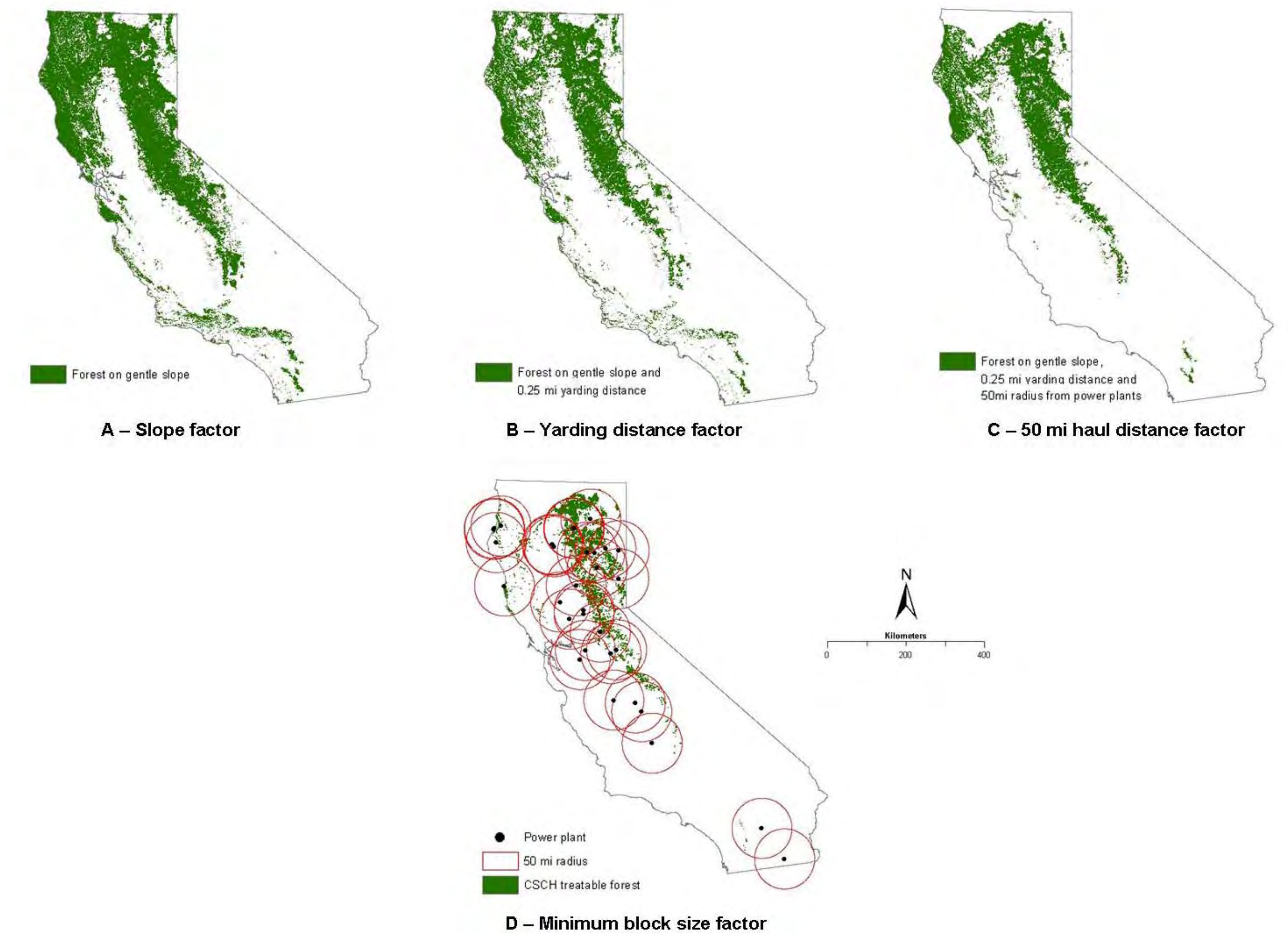

Figure 5-14. Addition of a fourth critical factor to determine forest lands suitable for CSCH fuel treatment: D - Minimum block size of 80 acres.

5.4.2 Economic analysis and potential role of carbon emission reduction credits

Costs for CSCH range widely depending on the treatment prescription, presence or absence of merchantable material in the prescription, region of the country, and the factors identified above (slope, yarding distance, haul distance, etc.). Here we use as a guide the values quoted in a recent broad-scale strategic assessment covering 15 states and a wide range of experience with HFR: the treatment analogous to CSCH had a cost range of $34-48/BDT (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003). Assuming from above that biomass of approximately 9.1 million BDT would be removed from the forest lands in scenario 1, treating all these forest lands would have a total cost of approximately $308 million (low) to approximately $435 million (high). Treating these forest lands in scenario 2, removing twice as much biomass, would have a cost of approximately $616 million (low) to approximately $870 million (high).

The value of this biomass for purchase by biomass facilities may be estimated at $36/BDT (Fried et al 2003), although market prices for fuel will vary somewhat by region depending on the number of biomass plants in operation and thus competition for fuel. For both scenarios, we estimate the revenue that CSCH on the forest lands in question would generate, and/or subsidy required, to remove the available biomass to biomass energy facilities.

In the first scenario, with removal of 9.1 million BDT biomass from California forest lands at high and very high fire risk, the fuel would have a total value of approximately $326 million, and thus range from generating a small net revenue of approximately $18 million (if value = $36/BDT and cost = $34/BDT), to requiring a total subsidy of approximately $109 million to treat all these lands (if value = $36/BDT and cost = $48/BDT). In the second scenario, with removal of 18.1 million BDT biomass, the fuel would have a total value of approximately $653 million, and thus range from generating a net revenue of approximately $36 million (if value = $36/BDT and cost = $34/BDT), to requiring a total subsidy of approximately $218 million to treat all these lands (if value = $36/BDT and cost = $48/BDT).

To attempt to investigate whether removal of hazardous fuel that results in reduced fire intensity and reduced carbon emissions (i.e. conservation of forest carbon stocks) makes economic sense, the following first-order calculations are presented. Assuming the higher costs for biomass removal as described above, to treat the 907 thousand ha estimated to be treatable using CSCH would require a per-hectare subsidy of $120 ($109 million total subsidy divided by 907 thousand ha) for removal of 10 BDT/ha, or $240 ($218 million divided by 907 thousand ha) for removal of 20 BDT/ha. Assuming commonly used prices of CO_2, would emissions reductions attributable to HFR activities be sufficient so that the sale of carbon credits from these projects could cover the per-hectare subsidy required?

Depending upon the price of carbon assumed (two commonly used values are $2.4/t CO_2 and $10/t CO_2), the quantity of carbon emissions that would need to be reduced through HFR in order to cover the per-hectare subsidies needed – essentially, to make high-cost CSCH a break-even activity – varies from as little as about 3 t C/ha to as much as 27 t C/ha (Table 5-2). Whether HFR could produce this order of magnitude of emissions reductions depends on baseline emissions from fires of varying intensities, and whether HFR prior to fire reduces the intensity of fires. In an analysis conducted for this project, the differences between net carbon emissions from medium-intensity fires and low-intensity fires across all forest types in California ranged from 10 to 75 t C/ha; the difference in emissions between high-intensity and low-intensity fires ranged from 27 to 75 t C/ha (Brown and Kadyszewski 2005). In other words, if HFR resulted in low-intensity forest fires rather than medium-intensity fires, there would be a reduction in carbon emissions attributable to HFR of 10-75 t C/ha; if the reduction was from high-intensity to low-intensity fires, the reduction in emissions would be from 27-75 t C/ha. The reduction in emissions that would need to be achieved by HFR in order to cover the per-hectare subsidies required, 3-27 t C/ha, is generally within the same range or lower. Thus it appears, in a preliminary analysis, that the order of magnitude in emissions reductions attributable to HFR, assuming commonly used prices for carbon offsets, is within the realm of practicality to cover subsidies needed for HFR – adding support to the argument for qualifying fuel reduction activities as carbon offset projects. It should be emphasized that this preliminary analysis needs further research, including collection of additional data on emissions from wildfires of varying severity, and policy discussion of what reductions in fire intensity and/or emissions should qualify as attributable to pre-fire HFR treatment.

Table 5-2. Quantity of CO_2 emissions reductions (t CO_2/ha and t C/ha) that would need to be produced by HFR activities in order to cover estimated per-hectare subsidies needed for CSCH.

Subsidy	$2.4/t CO_2		$10/t CO_2	
	t CO_2/ha	t C/ha	t CO_2/ha	t C/ha
$120/ha	50	14	12	3.3
$240/ha	100	27	24	6.5

5.5 Analysis of low-severity and mixed-severity fire regime forests treatable with CSCH

The fourth component of this analysis addresses fire risk issues in the forest lands that are designated with low-severity and mixed-severity fire regimes. Decades of fire suppression practices, resulting in unnatural fuel accumulation and severe wildfire in western forests, are particularly associated with the dry ponderosa pine forest type (Schoennagel et al. 2004). According to Schoennagel et al., dry ponderosa pine forests are in urgent need of ecological restoration and fire mitigation. Historically, frequent and low-intensity fire maintained open stands in low-elevation ponderosa pine; the surface fuel layer, dominated by grasses and needles, usually dries easily, resulting in frequent low-intensity surface fires. Disturbing this historical fire regime in these forests through fire suppression has resulted in build-up of ladder fuels at intermediate heights that carry ground fires into the crown, where they can lead to large, catastrophic fires. Mixed-severity fire regimes occur mostly at mid elevation, in forest stands with variable tree species and densities defined as mixed conifer forests. For these forests accumulated fuel and climate affect the frequency, severity and size of fires. The impact of suppression practices on fuel loads in these forests varies depending on the tree composition of the forest stand. To restore historical stand structure of ponderosa pine and mixed conifer forests, mechanical HFR treatments are recommended.

For this part of the analysis, forest areas with low-severity and mixed-severity regimes that urgently need CSCH treatment were identified. The first step was to extract forest categories that likely experience low-severity and mixed-severity fire regimes, based on the WHR land cover classification. Three forest categories were recognized from the CDF-FRAP 2002 land-cover map: ponderosa pine forest, Sierran mixed conifer forest and Klamath mixed conifer forest. A new map, composed from these forests designated with low and mixed-severity fire regimes, was called ‘Ponderosa pine and mixed conifer forest’ (Figure 5-15). The total area of low-severity and mixed-severity fire regime forests in California was estimated at **approximately 2.8 million hectares**.

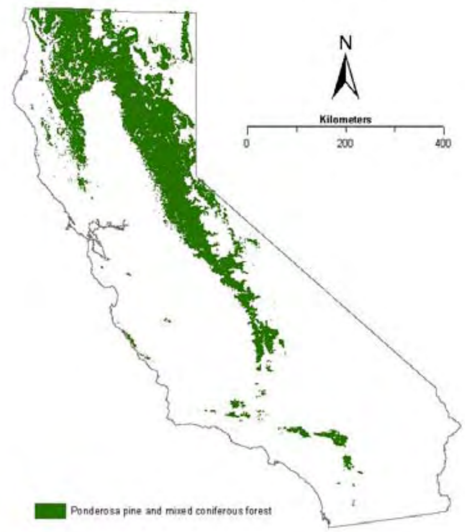

Figure 5-15. California's Ponderosa pine and mixed coniferous forests designated with low and mixed-severity fire regimes.

As above, applying three sequential factors of maximum 40% slope, maximum 0.25 miles yarding distance, and maximum 50-mile radius from existing power plants, resulted in an estimate of **approximately 509 thousand hectares** of dry ponderosa pine and mixed conifer forests that would be available for CSCH treatment (Figure 5-16).

To restore the historical stand structure and fire regime in dry ponderosa pine and mixed coniferous forests, we assume that 10 BDT per hectare would be removed from the areas accessible for CSCH treatment. This would result in **approximately 5.1 million BDT biomass** removed associated with approximately 2.5 million t C initial removals. Removing 5.1 million BDT biomass from these forests implies a fuel value of approximately $183 million (fuel price of $36/BDT, as above), and thus ranges from generating small net revenue of approximately $10 million (if value = $36/BDT and cost = $34/BDT), to requiring a total subsidy of approximately $61 million to treat these forest lands (if value = $36/BDT and cost = $48/BDT).

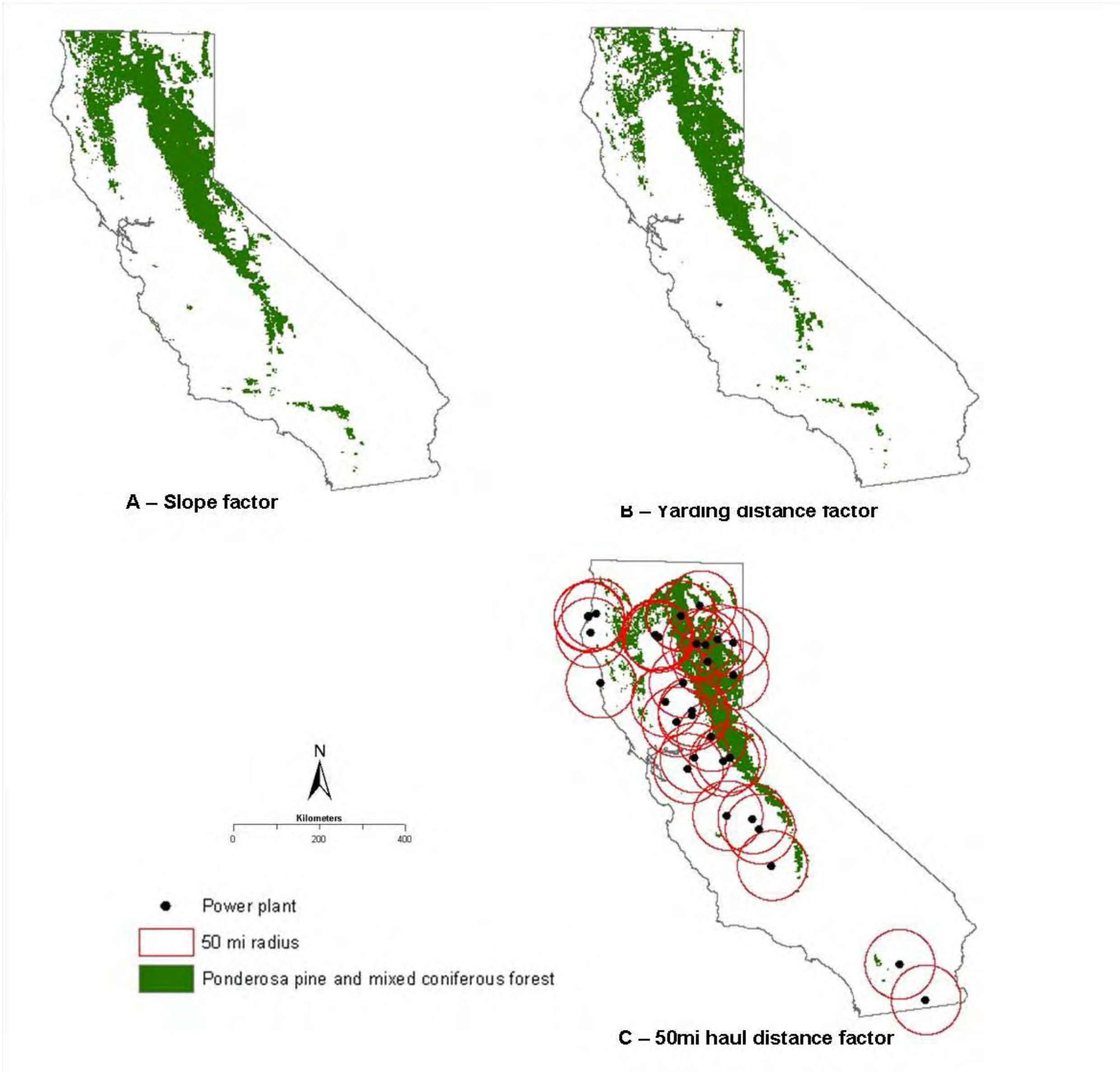

Figure 5-16. Critical factors to determine forest lands with low-severity and mixed-severity fire regimes, suitable for CSCH fuel treatment: A - Slope less than 40%; B- Yarding distance less than 0.25mi; C- Distance from existing power plants less than 50 miles.

Finally, adding the fourth constraint of minimum block size to justify move-in costs (Figure 5-17), and excluding all otherwise qualifying treatment blocks of less than 80 acres, results in the following numbers:

- **Approximately 368 thousand hectares** of dry ponderosa pine and mixed conifer forests would be available for CSCH treatment;
- With HFR removal of 10 BDT/ha, treatment would yield **approximately 3.7 million BDT biomass** associated with 1.85 million t C initial removals.

- Removing this biomass would range from generating a small net revenue of approximately $7.4 million to requiring a total subsidy of approximately $44 million.

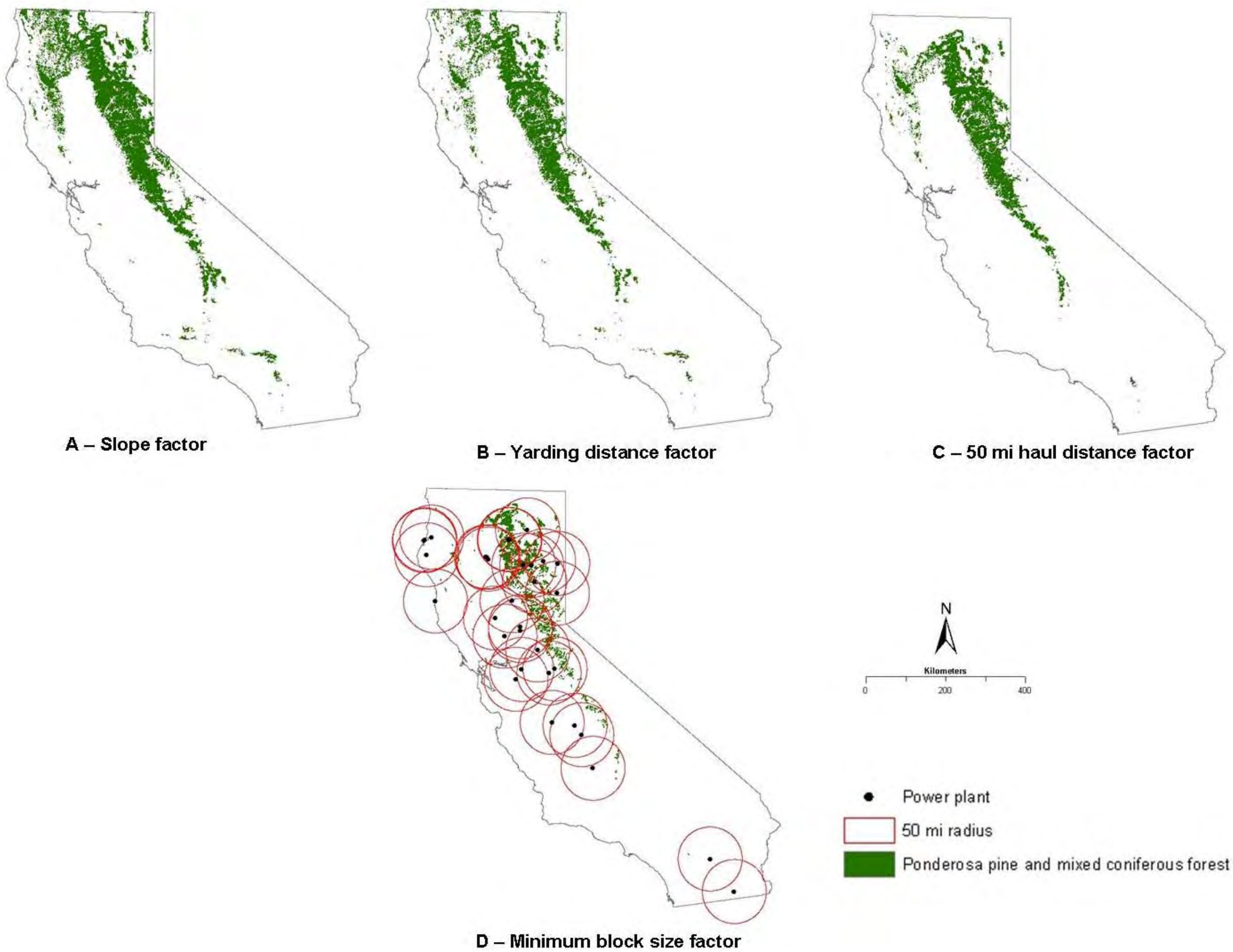

Figure 5-17. Addition of a fourth critical factor to determine forest lands with low-severity and mixed-severity fire regimes, suitable for CSCH fuel treatment: D – Minimum block size of 80 acres.

5.6 Next steps

The preliminary analysis presented here highlights needs further research, policy discussion, and consensus-building among the diverse stakeholders with an interest in forests and fire. Further research and analysis is needed, particularly in the following two areas.

5.6.1 Refinement #1: Analysis of other HFR treatment types

In reality a much greater range of treatment types than only CSCH is available for fuel reduction and/or removal. Each treatment type has its own ideal conditions for use, constraints on use, costs, product yield and thus revenue to offset costs, and environmental (air quality, sedimentary, and greenhouse gas emission) implications. Some treatments leave the fuel on site or simply change its form, but may be applied on sites that are relatively more inaccessible either from a technical (terrain, slope, distance to roads) or economic (hauling distance) point of view. Thus a more comprehensive model is needed to answer the questions:

- What factors in addition to slope, yarding distance, distance to biomass plants determine the choice of treatment type and technology—mix of diameter classes to be removed, volume and number of stems in the submerchantable and merchantable categories, distance to processing facilities for merchantable material, other factors?
- What is an appropriate decision rule for each factor? In treating the slope factor, this analysis assumed CSCH could be applied on slopes < 40%. An analysis based on meeting constraints ignores the other side of each decision rule: excluding lands of >40% slope or >0.25 miles yarding distance only means these lands are not available for CSCH, not that they are excluded from all HFR treatment. On slopes > 40% or at greater distance from roads, other treatments might be available that leave fuel on site but still reduce fire hazard (cut-pile-burn, cut-lop-scatter, prescribed fire etc.).
- What are commonly accepted cost ranges for each treatment type and technology, in $/acre or $/bone dry ton (BDT) for submerchantable material and $/MBF or $/CCF for merchantable?
- What revenues are available from utilization of submerchantable and merchantable material from these projects, and what effects do revenues have on the factors and decision rules used to select treatments? For example, by how much will a greater volume of merchantable material in the prescription increase the yarding distance or distance to a processing facility that is economically feasible?

Most HFR treatments in fact involve a mix of submerchantable and merchantable material, with the value of merchantable material sometimes “subsidizing” the high cost of removing a large number of submerchantable stems, and both submerchantable and merchantable being part of the prescription to achieve a desired condition of spacing, residual basal area per acre, improved forest health, improvement in Torching Index and Crowning Index, etc. Including merchantable material would make more acres accessible for treatment. Thus the estimates here, focusing only on one objective and a single treatment targeting the submerchantable biomass fuel, can be taken as conservative.

5.6.2 Refinement #2: GHG emissions from wildfire, and eligibility of HFR as a carbon offset activity

The suggestion that HFR might produce sufficient emissions reductions to pay for currently uneconomic CSCH treatments, if these emissions reductions were marketable at commonly used prices for CO_2 credits, is a starting point for further study. This suggestion was based on first-order estimates of the difference in CO_2 emissions between low-, medium- and high-intensity fires, and the assumption that HFR treatment might be credited with turning what would have been a high- or medium-intensity (perhaps crown) fire into a low-intensity (perhaps ground) fire. If so, the emission reductions could be credited to the HFR treatment and potentially marketed as a carbon-offset project.

To substantiate this hypothesis, several areas of study are needed. First, work is needed to develop baselines for various wildfire-prone forest types. These baselines will serve as the reference case against which activities to reduce fires would be compared to estimate the potential carbon credits. Such baselines need to include field data and models to quantify the likelihood of fires occurring (e.g. fire-return interval) as well as the effects of fire on greenhouse gas emissions for the forests under different intensities of fire (how much of carbon stock is burned by fire intensity and stand structure). Field data might include measurements of post-fire forest carbon stocks for comparison to unburned areas; measurements in past fires of varying intensities; measurements of areas where fuel loads were reduced prior to fire to quantify how much treatment reduced the loss of carbon stocks; and evaluation of non-CO_2 greenhouse gas emissions such as CH_4 and N_2O, also likely to be released in wildfires though to varying extents depending on the type and intensity of fires.

Second, further scientific research as well as policy discussion and consensus-building are needed around the question of what reductions in fire intensity and/or greenhouse gas emissions should be attributable to pre-fire HFR treatment. Intuitively reducing ladder fuels or crown density should reduce the probability, intensity, and extent of wildfires and thus the loss of forest carbon stocks and other greenhouse gas emissions; but by how much? With a probabilistic phenomenon such as fire, it is not possible to demonstrate that an area treated with HFR would have burned in the absence of treatment, and released X tons of CO_2 equivalent to the atmosphere. Nor in the with-treatment scenario is the goal necessarily to avoid fire and its associated emissions, only to reduce the intensity of fire or its extent. Many fire models are currently in use to evaluate probability and impacts of fire under different assumptions, but these models produce highly variable outputs and consensus among models is lacking, and most do not address greenhouse gas emissions from fire. Therefore the process of deciding what types of HFR treatments should be eligible to qualify as carbon offset projects, and assigning values to the greenhouse gas emission reductions attributable to HFR, will involve considerable scientific as well as political consensus-building – even among stakeholders who more or less agree it would be desirable to reduce fuel loads and treat more acres by improving the overall economics of HFR through qualifying these projects for CO_2 credit markets.

Bringing this refinement together with the last, different HFR treatments and technologies could be evaluated in terms of their greenhouse gas emission impacts: for example, "CSCH" would be assigned a triple emission reduction benefit through reduced emissions from wildfire, reduced emissions from fossil fuel-generated electricity due to electricity generation in biomass facilities, and enhanced carbon sequestration in the residual forest stand. Prescribed fire or cut-pile-burn could be assigned a quantifiable benefit for reducing the incidence or intensity of wildfires, but would still put a greater portion of the forest carbon removed in the treatment into the atmosphere.

When potential utilization of both submerchantable biomass and merchantable material from HFR treatments is considered, emissions reduction credits become one of a set of values – along with merchantable material, biomass fuel value, green power incentives, and even other marketed ecosystem services enhanced by these treatments -- that would improve the overall economics of HFR and help federal, state and private landowners to mount a more effective response to the wildfire problem.

Finally, further work would then be needed to develop carbon accounting methods and field protocols for actually quantifying the potential carbon credits for a variety of fuel treatments by forest types. This calculation would include the reduction in greenhouse gas emissions from displacing some quantity (MWh) of electricity that would otherwise be generated using fossil fuels. Such methods and protocols would need to be cost effective, transparent, and reproducible.

These refinements will be addressed through additional field data collection, modeling, analysis, and stakeholder discussions in the second phase of the West Coast Regional Carbon Sequestration Partnership.

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